



## RESEARCH AND CLASSIFICATION OF SURFACE AND INTERNAL DEFECTS OF CERAMIC CUTTING TOOL

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### ABSTRACT

System approach to studying of causes of infringement of operational characteristics tool ceramic materials on the basis of complex researches and systematization of their volume and superficial defects is presented in article. The main directions of improvement of tool ceramics are allocated.

**Keywords:** ceramics, cutting tool, fragile destruction, diamond processing, durability, structural defects, coatings.

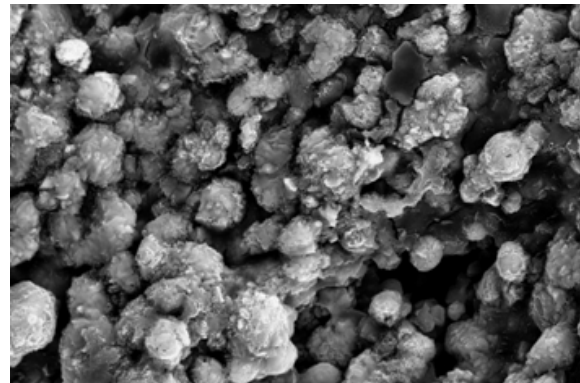
### INTRODUCTION

Domestic and foreign research, conducted in the field of studying of the causes of destruction of tool ceramics, show that the main cause of operability loss of ceramics in the process of operation is brittle fracture [1-4]. The failures caused by brittle fracture account up to 55% of all failures of ceramics when turning and up to 80% when milling. The reason for this are the low strength properties and responsivity of ceramics to cyclic loads and thermal shocks, which are the result of volume and superficial defects in the structure of ceramics, formed at different stages of its life cycle [5, 6].

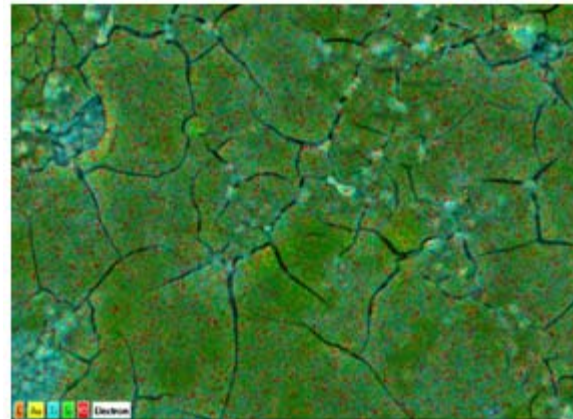
The aim of this work was complex research and systematization of volume and surface defects of tool ceramics, which could be the starting point and the system of scientific approaches to improve its performance properties.

### STRUCTURAL FEATURES OF TOOL CERAMICS

In the analysis of volume and surface defects of tool ceramics it is necessary to rely on the classic provisions of the theory of brittle fracture of solids. So, from the standpoint of the theory of Griffiths, insufficient strength of isotropic solids is caused by the presence of discontinuities or defects, the main dimensions of which are large compared to the intermolecular distances, i.e. the presence of microcracks in the material. Applying Griffiths failure theory on ceramic tool materials, taking into account the availability in their volume of a granular structure and structural heterogeneity, we can conclude that in the volume and on the surface of the cutting plate there are always conditions of formation and development of cracks. Physical objects for formation of cracks are the interfaces of the grains and inclusions of another chemical composition (Figure-1). These boundary surfaces are stress concentrators and the source groups of points, from which begins the origin and development of cracks in the volume of the ceramic die (Figure-2).



**Figure-1.** Photomicrograph of the surface destruction of tool ceramics after the bending test.



**Figure-2.** Reflection of the polished fracture surface of tool ceramics after the bending test.

Considering the different models of development of cracks in solids, we assume that in the initial time there was given some spreading of cracks of finite length. This is consistent with the experimental data of the research of ceramic materials at different stages of the technological

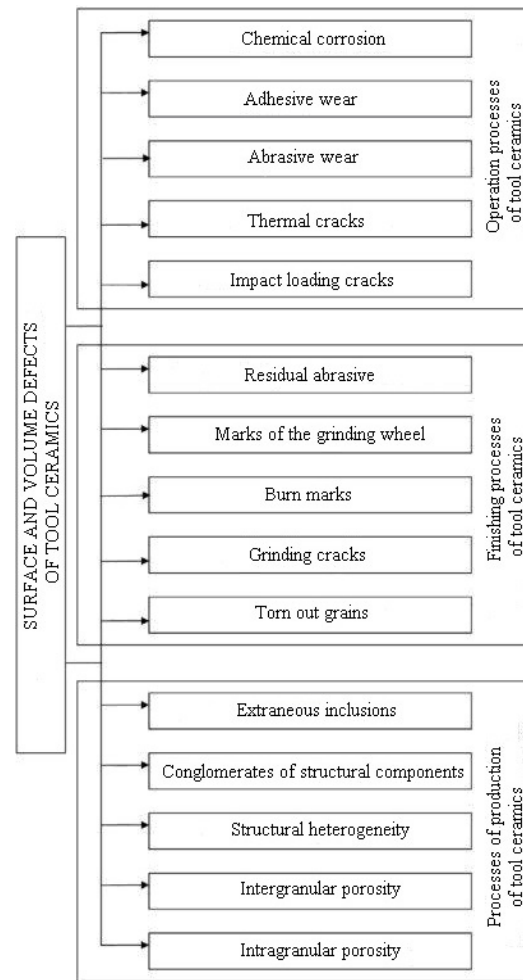


process. Any ceramic material, whatever pre-treatment it was subjected to, always has some structure imperfections. Taking into account granular structure and structural heterogeneity of ceramics it is reasonable to make the assumption that the weakest points of the ceramic die are the interfaces between ceramic grains and between the grains and inclusions of different chemical composition. At the interface between the grains is formed the front of inner stresses, concentrate the vacancies, arise nonequilibrium thermodynamic potentials. In the unloaded ceramics these forces are balanced in the volume of ceramic die with interatomic interaction forces.

Considering the model of structurally inhomogeneous tool ceramics, we assume that microcracks are localized at the grain boundaries of the ceramic material. In the same ceramic material, despite the homogeneity or heterogeneity of its microstructure, there are no grains identical in size or shape, as can be seen by studying the micrographs of the samples. The grains in the ceramic die are arranged randomly and contact each other under developed and arbitrarily located in space surfaces. Therefore, in the same way at the grain boundaries will be aligned the microcracks in the ceramic die.

### CLASSIFICATION OF DEFECTS OF TOOL CERAMICS

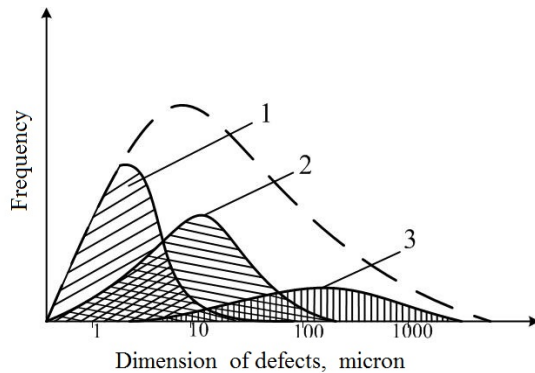
Basing on the analysis of works of domestic and foreign scientists and research [5, 6] conducted in MSTU "STANKIN", in the classification of surface and volume defects of tool ceramics is built upon the technological principle of formation of a defect at a certain stage of the life cycle - in the manufacturing (pressing and sintering), finishing (diamond sharpening and fine-tuning) and operation (Figure-3).



**Figure-3.** Systematization of surface and volume defects of the tool ceramics.

For example, defects arising in the process of pressing and sintering of ceramics include intragranular porosity, intergranular porosity, and structural heterogeneity, conglomerates of structural components, foreign particles and impurities. Typical defects of finishing of tool ceramics are torn out grains, grinding cracks, traces of the grinding wheel, burns and residual abrasive in the microroughnesses. Defects arising during operation of the cutting tool, include planar and thermal cracking, abrasive and adhesive wear and chemical corrosion.

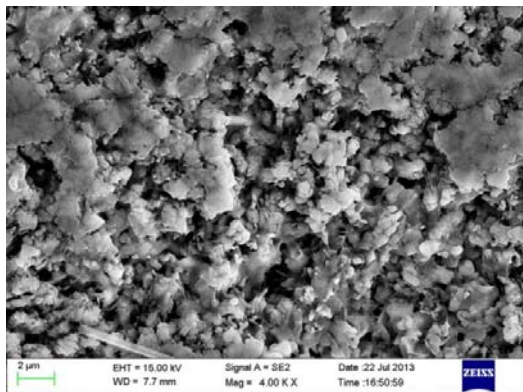
A typical distribution curve of the defects of tool ceramics, determining the level of strength of the product, is shown in Figure-4. The dashed line shows the additive effects of different types of defects [1].



**Figure-4.** The size distribution of defects at various stages of the technological process: 1- grain boundaries, triple points, crystallites; 2-agglomerates, chemical heterogeneity, mineral inclusions; 3-traces of organic inclusions, defects of pressing, machining defects.

#### DEFECTS OF TOOL CERAMICS ARISING IN THE MANUFACTURING PROCESS

It is well known that modern tool ceramics from the point of view of materials science is a structurally heterogeneous environment of a ceramic die, in which are uniformly distributed inclusions of oxides of silicon, titanium, zirconium and other chemical elements (Figure-5). Ceramic die is mostly made on the basis of aluminum oxide or silicon nitride. There is also a large variety of types of tool ceramics with a chemical composition that is slightly different from the basic species [3-5].



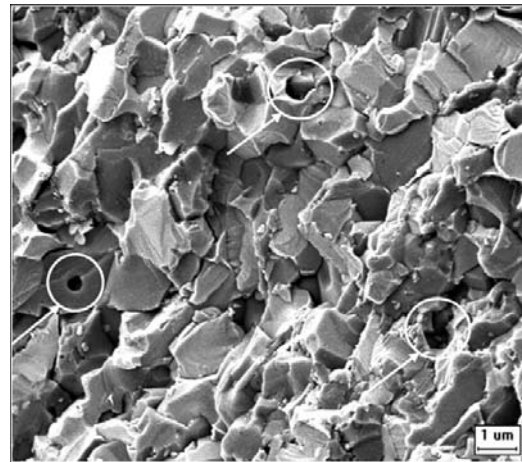
**Figure-5.** SEM micrograph of structural heterogeneity of tool ceramics.

The reduce of porosity is an important issue of technology of manufacturing of ceramics, because the pores are the concentrators of stress and vacancies. Properties of ceramics are determined by the overall porosity and its type (closed and opened).

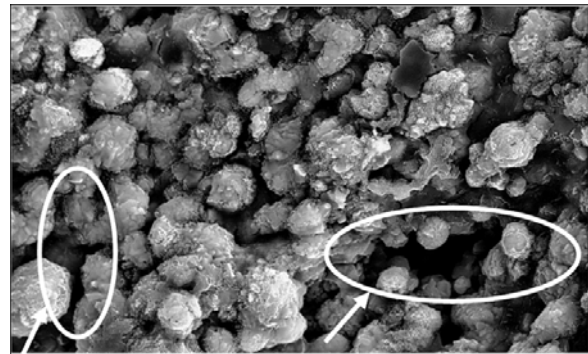
By origin it is possible to classify the following types of pores: technological pores formed during

pressing: interparticle, intraparticle, layering pores; technological pores formed during heat treatment: shrinkage and thermal; secondary, diffusion, coalescence, dislocation, capillary pores.

Intragranular porosity (Figure-6) and intergranular porosity (Figure-7) are finally formed in the ceramic die as a result of sintering [5, 6]. During the sintering of the ceramic material take place several physico-chemical processes and the sintered product gets certain properties. Thus there is thickening and hardening of the ceramic due to the transfer and redistribution of the material.



**Figure-6.** SEM micrograph of intragranular porosity of tool ceramics.



**Figure-7.** SEM micrograph of intergranular porosity of tool ceramics.

The concept of structural heterogeneity for tool ceramics is a fundamental physical property and has a wider meaning than for conventional metals and alloys. Under structural heterogeneity of tool ceramics should be understood not only the presence of inclusions of different chemical composition with boundaries in the material volume, but also the presence of structural defects of





different types: pores, cracks, cuts, sinks, etc. in the volume of material and on the surface of tool plates.

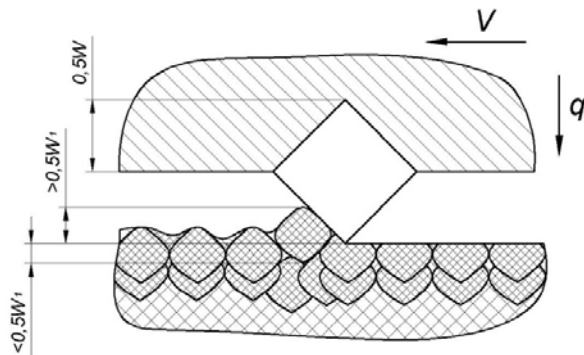
### DEFECTS OF TOOL CERAMICS ARISING IN THE FINISHING PROCESS

Since the ceramic plates are products with accurate dimensions, they require the final machining. The most effective method of finish machining of tool ceramic are diamond grinding and lapping. The processes that occur during stock removal in diamond grinding, have a significant impact on the operational characteristics of the cutting plate. The defining role of defects in the formation of the mechanical properties of ceramics is generally accepted [1-3].

In the favorable modes of grinding ceramic plate is not in contact with a post of diamond grinding wheel and the cutting grain is embedded into the material by 0.2-0.4 of the protruding part [4].

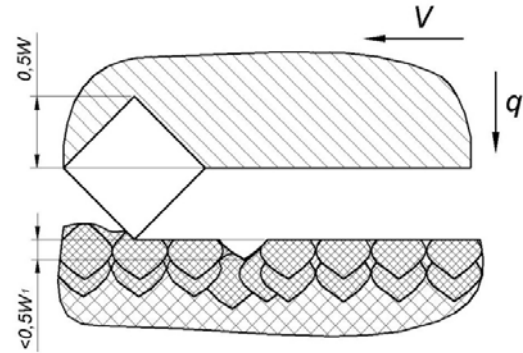
The analysis of the process of finishing of the tool ceramics allows noting the following important features.

a) Not all of the grains of the ceramic material will be torn out from the machined surface of the plate, but only those that protrude above the surface on more than  $0.5 W_1$  (Figure-8). Here  $W_1$  is the average grain size of the ceramic material.



**Figure-8.** Scheme of out tearing of a single grain of the processed ceramic material.

b) After the tearing out of grain of ceramic material at the place of its location will be formed a crater, having the size and shape of the inverse-depth parts of the grain (Figure-9). As the size of the in-depth part of the grain in our model is always less then the size of the protruding one, as the result of grinding the roughness of the machined surface will decrease. The depth of the single crater is always less than half of the nominal size of the ceramic grain.

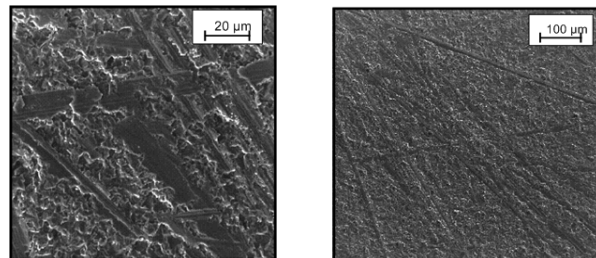


**Figure-9.** Scheme of the crater in place of the missing single grain of the processed ceramic material.

c) The number of torn grains of ceramic material and the number of craters on the treated surface depend on the homogeneity of the structure and granularity of tool ceramics.

Another characteristic defect of finishing is the so-called grinding microcracks. Practice shows that microcracks form on the surface of ceramics even in the soft modes of grinding, and it reduces the level of its mechanical strength. The destruction of the machined ceramics is usually initiated by a critical surface defect (the weakest link). The reduction of the size and number of processing defects in the surface layer can be achieved, for example, through the use of lapping with a gradual decrease of granularity of the paste.

Another typical defect are marks of the grinding wheel (grinding scratches) remaining on the surface of the cutting plate after finishing treatment. (Figure-10) There is a direct relationship between the size of the grinding scratches and the grain size of the grinding wheel and lapping powder. The reduction of the grain size is accompanied by a decrease in the depth and width of the grinding scratches.



**Figure-10.** Typical view of the surface of oxide-carbide ceramics after diamond grinding.

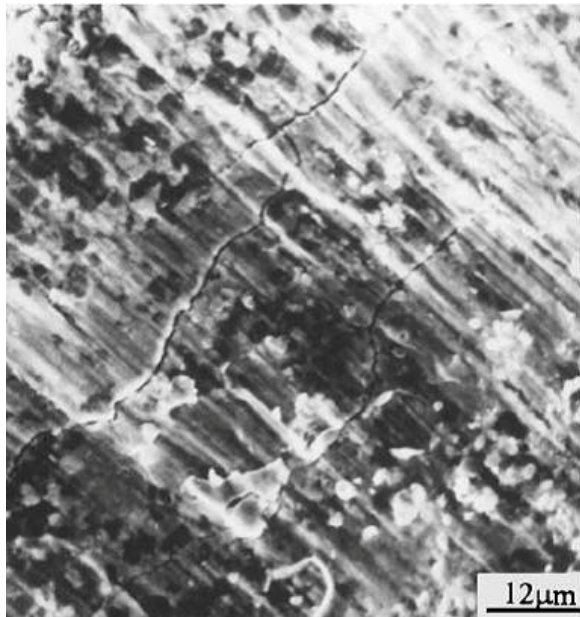
Forming on the surface of the cutting insert the mesh scratches, grinding scratches increase its roughness and may increase the frictional force between coming chip and the surface of the insert. The negative effect of



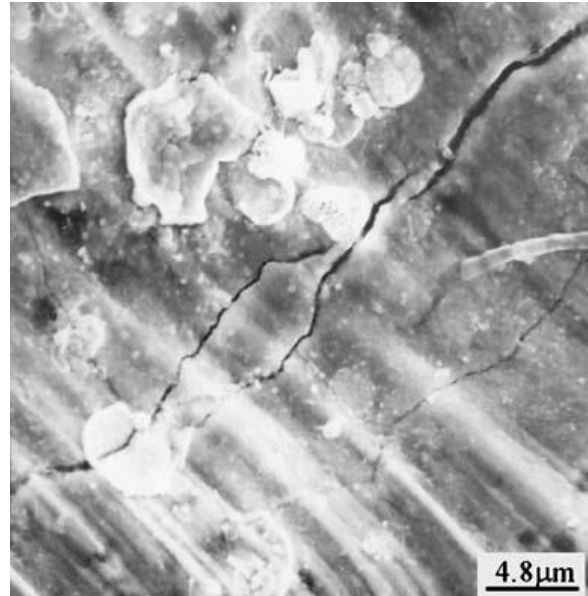
grinding scratches on the properties of the ceramics is that traces of the grinding wheel, being in size, in particular, in depth, much bigger than the grains of ceramics, create on the surface of the plate the estimated sources and trajectories for the formation and development of crack front during operation of tool ceramics.

### DEFECTS OF THE TOOL CERAMICS ARISING IN THE PROCESS OF OPERATION

The study of the tool ceramics from the point of view of structurally inhomogeneous material allows noticing that even in the initial state ceramics contains microcracks, which are localized at the grain boundaries of the material. The grains in the ceramic die are arranged randomly and are in contact with each other under developed and arbitrarily located in space surfaces. Similarly, in an arbitrary order along the grain boundaries appear microcracks in the ceramic die. Under cyclic loading conditions and the intermittent nature of the cut (for example, when milling) on the surface of the cutting plates appear cracks (in the literature these cracks often called planar fractures), resulting in a failure of ceramics in the form of brittle fracture (Figures 11, 12) [2]. Basing on the above facts, a sufficiently reasonable assumption that can be made is that these cracks are a development of existing microcracks, which are located at the grain boundaries.



**Figure-11.** SEM micrograph of the formation of cracks on the front surface of the cutting insert.



**Figure-12.** SEM micrograph of the spread of micro cracks on the surface of the cutting insert.

Another typical defect of ceramics, appearing in the course of operation is thermal cracking. The cutting process is accompanied by severe plastic deformation of the processed material and friction at the contact surfaces of the tool, resulting in a large amount of developed heat. Ceramic tools are used typically at high speeds, leading to the appearance of high local temperatures on the front and back surfaces of the tool. Thermophysical properties of ceramic tool (heat capacity, thermal conductivity, and thermal expansion) determine the conditions of the thermal load of the cutting edge associated with the balance of heat flows into the cutting tool, chips and processed material, as well as the ability of the cutting tool to resist thermal stresses without failure. Thermophysical properties determine the thermal stability of ceramics and its ability to resist thermal cracking.

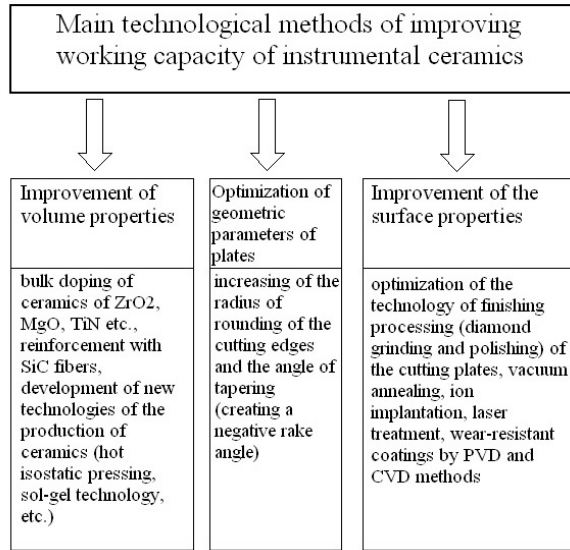
### THE MAIN DIRECTIONS OF INCREASING OF EFFICIENCY OF TOOL CERAMICS

Conducted complex of research, the results of which are summarized above, as well as the proposed classification of volume and surface defects of tool ceramics, show that the main directions of improvement of tool ceramics today should be related to the improvement of its mechanical properties, including minimizing the defects formed at various stages of manufacture of the plates and increasing its thermal conductivity.

A wide range of existing technological methods of improving instrumental ceramics can be divided into 3 groups (Figure-13): improving of volume properties [4, 5], optimization of geometric parameters of plates of tool



ceramics [1, 6], the improvement of the surface properties [2, 3].



**Figure-13.** Directions of improvement of the tool ceramics.

The most attractive (in terms of adaptability and versatility efficiency) for practical application in real conditions of domestic production is directed impact on the surface of the ceramic layer by coating and/or modification (ion implantation and laser alloying), allowing to transform the properties of the surface and surface layer of the original die. An important advantage of this concept is that it can successfully be used for ready-made ceramic products (as an additional operation in the technological chain of manufacture) when the implementation of other areas in most cases is impossible. This will be achieved by three main effects: healing the surface defects of technological origin; creating in the surface layer of ceramic die a barrier, which hinders the emergence of operational defects; forming of a barrier that prevents the expansion of internal cracks on the surface (in case of their presence or origin) and limiting the supply of external energy to the mouth of cracks.

## CONCLUSIONS

Thus, the work proposes classification of volume and surface defects of tool ceramics, which was based on the technological principle of their occurrence, as a unifying trait common to all types of tool ceramics. The study provides an opportunity to create a system of scientific views on the problems of improving and expanding of the field of application of the ceramic tools.

All areas of development and improvement of tool ceramics are associated with the improvement of its

mechanical properties, mainly due to minimization of defects formed at different stages of its life cycle.

Most of these defects are formed in the surface layer of ceramics during manufacturing and operation. This fact demonstrates the need for the development and application of technological methods of targeted exposure on the surface layer of the ceramics by coating and/or modification of tool ceramics, which is used after its sintering and shaping, i.e. operations in which appear technological defects.

It should be clearly understood that there can not be developed a universal technological method that is applicable to various types of tool ceramics. A wide range of compositions of tool ceramics - oxide, nitride, mixed, reinforced, sialon, as well as expanding area of their use (due to application of new materials in mechanical engineering, increasing cutting speeds and complexity of the trajectories of cut, etc.), necessitate the development and implementation of an integrated systems approach to the solution of problems of formation of superdense (defect-free) tool ceramics with high mechanical and operational properties.

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